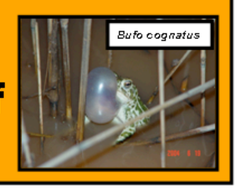
Climate and agricultural influences on diversity and physiological fitness of amphibians in playa wetlands

Authors: S. T. McMurry[1], L. M. Smith[2], T. A. Anderson[1], K. D.Dupler[1], D. M. Ghioca[2], M. B. Gutierrez[1], J. Tsai[2], and L. S. Venne[1]

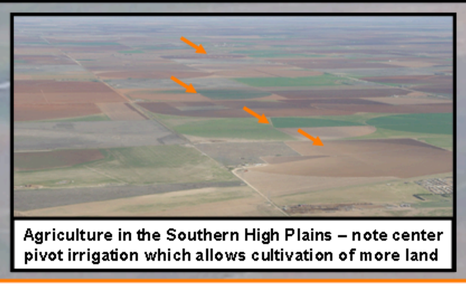
Affiliations: The Institute of Environmental and Human Health (TIEHH)[1] and Department of Range, Wildlife, and Fisheries Management[2], Texas Tech University



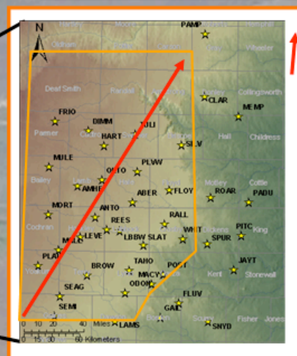
Abstract

Our study is focused on the effects of and interactions between agricultural activities and climate change on playa wetlands and their resident amphibian communities in the Southern High Plains (SHP). Cultivation results in significant deposition of sediments in playas embedded in watersheds dominated by cropland, typically burying greater than 100% of the hydric soil in most cropland playas. This results in a reduced hydroperiod that can have negative effects on amphibians as dictated by their individual life history strategies. In addition, we found that size (69% greater), volume (76% greater), and density (48% greater) of playas increase and sediment depth (52% less) in playas decreases across a southwest (SW) to northeast (NE) gradient on the SHP. This SW–NE gradient is characterized by increasingly finer-textured soil (more resistant to erosion), increased rainfall, and decreased temperature.

Water loss rate in playas is correlated with sediment depth ($R^2 = 0.2$) and the amount of cultivation in the watershed, which in turn correlates with a non-random increase in amphibian community richness ($R^2 = 0.73$). Typically, the amphibians most sensitive to reductions in hydroperiod are the less abundant species and those with longer periods of larval development. These results suggest that loss of playas and biodiversity of amphibians in playa wetlands will follow a predictable pattern from SW to NE. Predicted changes in climate on the SHP toward hotter and drier conditions will potentially accelerate this loss of playas and biodiversity. Interestingly, *Spea bombifrons*, *S. multiplicata*, and *Bufo cognatus* are the most abundant amphibian species in playa wetlands and appear to be the most resilient to reduced hydroperiods. However, recent results for these species suggest a fitness tradeoff associated with residing in cropland playas. For example, *S. bombifrons* and *S. multiplicata* collected from cropland playas show marked differences in body size and splenic cellularity, particularly during larval stages. Tadpoles collected from grassland playas are typically larger (30–60%) and have more splenocytes (250–1200% greater) than those from cropland playas. In addition, the same group of toads tends to have a greater proportion of polyunsaturated fatty acids (ca. 50% greater) if originating from grassland playas than cropland playas, suggesting that grassland amphibians could potentially survive longer under periods of starvation as is often encountered between the long periods between rainfall events. All of these results suggest that sedimentation of playas is having a negative influence on amphibian fitness and biodiversity in playa wetlands. Projected changes in climate will only augment the negative effects of sedimentation.



Agriculture in the Southern High Plains – note center pivot irrigation which allows cultivation of more land



= Gradient of increasing rainfall, decreasing temperature, and finer textured soil.

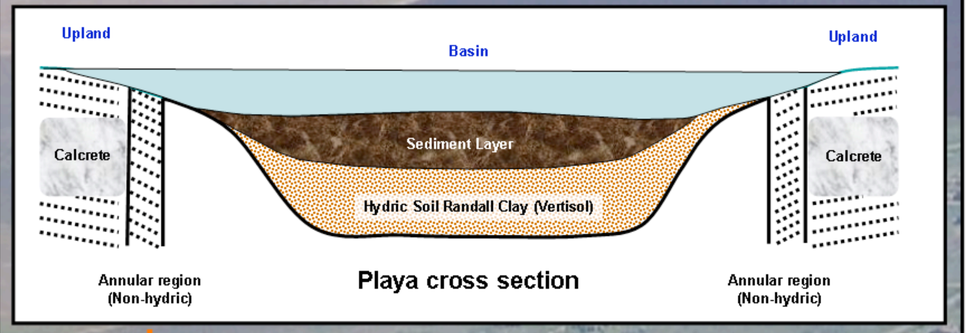
Ca. 25,000 playas

Intensive agriculture

Semi-arid environment

Heavy mining of Ogallala aquifer

40 miles



Sediment washing from cropland results in overall loss of playa volume, leading to a reduction in hydroperiod. Reduced hydroperiod results from increased surface area (increased evaporative loss), absorption by sediments, and loss through the more porous upland soil (beyond the hydric soil boundary).

Table 1. Means (2003 & 2004) of playa characteristics In two soil texture zones in the Southern High Plains.

	Grassland		Cropland	
Factor	Medium	Fine	Medium	Fine
N	5	34	20	18
Area (ha)	6.5	13.7	8.9	11.5
Basin depth (cm)	59	49	54	44
Volume ($m^3 \times 10^3$)	31	67	39	42
Sed. depth (cm)	20	8	53	31
Sed. vol. ($m^3 \times 10^3$)	12	13	38	30
Volume loss (%)	53	29	231	137

Body mass, length, and body fat of *Spea* spp.

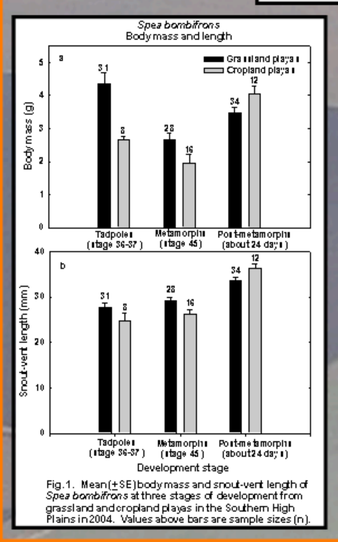


Fig.1. Mean (±SE) body mass and snout-vent length of *Spea bombifrons* at three stages of development from grassland and cropland playas in the Southern High Plains in 2004. Values above bars are sample sizes (n).

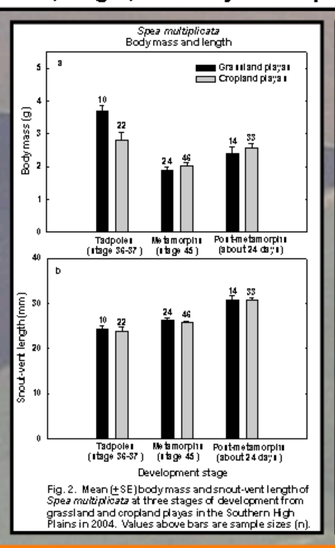


Fig. 2. Mean (±SE) body mass and snout-vent length of *Spea multiplicata* at three stages of development from grassland and cropland playas in the Southern High Plains in 2004. Values above bars are sample sizes (n).

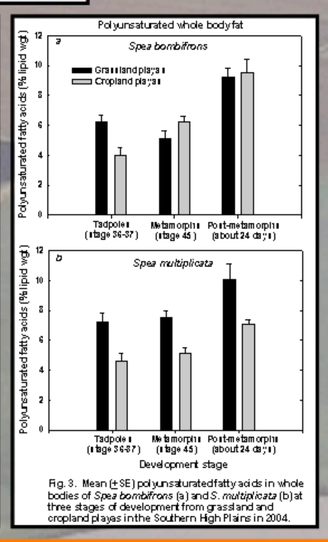


Fig. 3. Mean (±SE) polyunsaturated fatty acids in whole bodies of *Spea bombifrons* (a) and *S. multiplicata* (b) at three stages of development from grassland and cropland playas in the Southern High Plains in 2004.

Individual Responses

Amphibians collected in cropland playas are typically smaller than those from grassland playas, particularly as tadpoles (Fig. 1 & 2; also see Gray and Smith, 2005).

Size differences may be related to shorter hydroperiods, greater density of amphibians (due to nestedness or fewer predators), or nutritional factors in cropland playas (Gray et al., 2004).

Evidence for a nutritional link supported by lower total amounts of polyunsaturated fat (PUF) in spadefoot toads (Fig. 3).

Immune system development is tightly linked to metamorphosis in amphibians, and our evidence suggests that smaller toads from cropland playas also have smaller spleens and perhaps more importantly, fewer total splenocytes, particularly as tadpoles (Fig. 4 & 5).

All of these results suggest a fitness advantage for grassland toads over cropland toads. Large body size is linked to increased reproduction and foraging fitness, and greater proportions of PUF would suggest an advantage during prolonged stress events like hibernation. Fewer numbers of splenocytes (primarily lymphocytes) in cropland toads indicates a breakdown in normal immune system development, which could be suggestive of a compromise in overall immunocompetence.

Immunity endpoints for *Spea* spp.

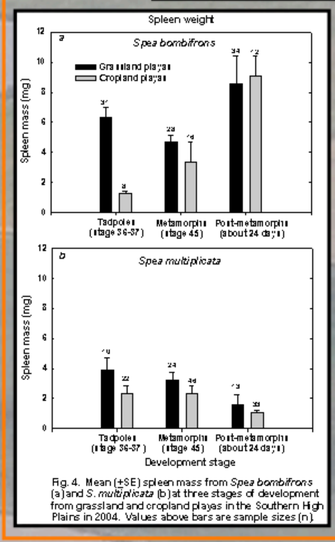


Fig. 4. Mean (±SE) spleen mass from *Spea bombifrons* (a) and *S. multiplicata* (b) at three stages of development from grassland and cropland playas in the Southern High Plains in 2004. Values above bars are sample sizes (n).

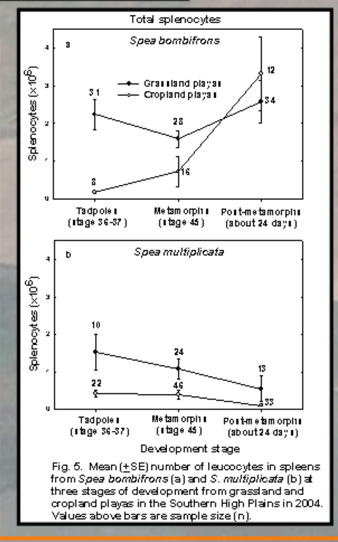


Fig. 5. Mean (±SE) number of leucocytes in spleens from *Spea bombifrons* (a) and *S. multiplicata* (b) at three stages of development from grassland and cropland playas in the Southern High Plains in 2004. Values above bars are sample size (n).

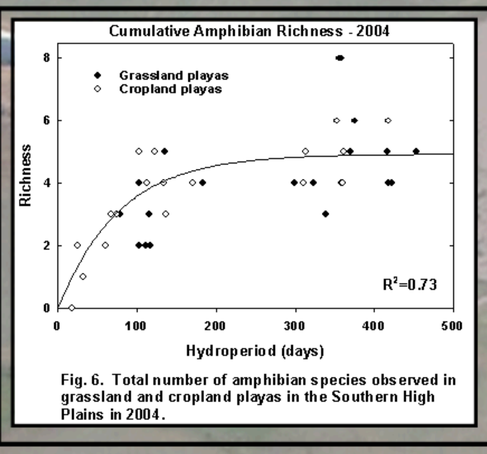


Fig. 6. Total number of amphibian species observed in grassland and cropland playas in the Southern High Plains in 2004.

Community Responses

Richness of amphibian communities in grassland and cropland playas show a strong relationship to hydroperiod (Fig. 6).

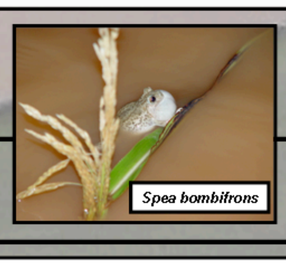
The relationship between richness and hydroperiod is non-linear, with a threshold response at hydroperiods less than approximately 100 days.

Further, the loss of species from individual playas follows a non-random pattern, with less common species and those with longer larval periods disappearing first (Table 2).

These results suggest that loss of amphibian diversity, and even individual species, is predictable based on reductions in hydroperiod.

Table 2. Proportion of playas within a hydroperiod category with a particular species of amphibian (Southern High Plains in 2003 & 2004; 80 total playa wetlands). Note complete loss of several species or reduction in occurrence of species below hydroperiods of 50 and 100 days.

Hydroperiod (days)	Spea	Buco	Bude	Pscl	Gaol	Buwo	Accr	Rabl	Raca	Amti
≤50	89	78	0	22	0	11	0	11	0	22
>50	91	87	6	68	16	13	6	38	10	46
≤100	91	72	0	53	6	3	3	25	0	47
>100	91	96	9	69	20	20	7	42	16	40



Synthesis of Results

Our research on playa wetland ecology in the Southern High Plains (SHP) is in large part directed toward understanding the influence of anthropogenic stress on playa function and associated biota. Two major stressors are constantly at play in this ecosystem; agriculture and climate.

Agricultural stresses include pesticides (for which little is known) and sedimentation (likely the most significant threat). Results of our studies and those of others clearly show differences in individual, population, and community level endpoints for amphibians between cropland and grassland playas. Differences between cropland and grassland hydroperiods and/or other watershed factors are regulating amphibian responses.

Climate in the SHP is characterized by seasonally intense and patchy rainfall events, with most precipitation occurring in May and June. Thus, although many playas within a given year receive enough precipitation to support hydroperiods of sufficient length for successful amphibian metamorphosis , many do not. Most climate change predictions for the SHP call for minimal changes in precipitation, but increases in annual mean temperature of 1 to 5°C. Increases in annual mean temperature will only further shorten playa hydroperiod, which is shown to be a strong driver of amphibian community richness.

As shown, sedimentation is greater in cropland than grassland playas (Luo et al., 1997; this study) which results in reduced hydroperiods in cropland playas, all else being equal (watershed, rainfall, etc.). As an example, model simulations (APEX) predict the number of wet days from May through August to differ dramatically between cropland and grassland playas, with cropland playas showing a threshold response of rapidly declining wet days after 16 years of unrestricted sedimentation, which has occurred in much of the area already (Fig. 7). Grassland playas on the other hand remain stable through 29 years, and then only lose about 14 wet days after 50 years. Simple mitigation strategies such as buffer strips slow sedimentation on cropland playas, shifting the threshold response by as much as 18 years. However, note that cropland playas still lose significant wet days at the end of 50 years (Table 2).

Thus, increased temperatures coupled with sediment loading in playas will act synergistically to shorten playa hydroperiod. As playas continue to fill with sediment, they will eventually become fossilized and incapable of holding water for any significant period of time (Fig. 7). The response will follow a predictable spatial pattern from south to north (following the natural gradient of climate and soil texture). So, in addition to alterations in individual fitness traits of amphibians between cropland and grassland playas, continued sedimentation of playas and increased temperatures will result in a predictable loss of species from amphibian communities. Cropland playas will be the first to succumb to these stressors, and given that they represent the bulk of playas on the SHP, the end result will be significant deleterious effects on amphibians and other wildlife that rely on playas.

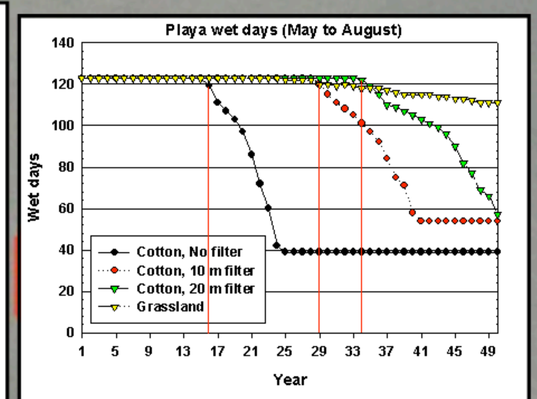


Fig. 7. Simulation results from APEX showing the total number of wet days in a playa from 1 May through 31 August under different landuse conditions and mitigation strategies.

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